

Geochemistry of hydrocarbon natural gases combining noble gases natural tracing and stable isotopes

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Gas may be considered nowadays both as a reliable tracer for the understanding of associated liquid hydrocarbons and as an economic target for itself. Isotopic measurements of both stable isotopes and noble gases give important clues to reconstruct the geological history of hydrocarbons from their generation to their accumulation. Recent analytical advances in carbon isotopes of natural gases (methane to butane and carbon monoxide) due mainly to the use of GC-C-IRMS allows us to reconstruct some of the physico-chemical processes which affect natural gas, instead of using these signatures as simple fingerprinting of origins as was the case some time ago. These reconstructions provide important information on both the origins and the dynamic behavior of hydrocarbon fluids between the source rocks and the accumulations in reservoirs. Correlating this methodology with other natural tracers increases the understanding of hydrocarbon history in sedimentary basins. Among other potential methodologies, noble gas isotopes may be new frontier tools, as their chemical inertia allows us to use them as precise tracers of sources and of simple associated physical processes (state of the phases, migration and leakage). Moreover, because some isotopes (^4He , ^{40}Ar for example) are produced by natural radioactivity, they represent geological clocks (Ballentine & O'Nions, 1994). We will present here recent case studies showing examples of geological interpretations obtained by coupling these geochemical tracers.

Summary on the origins of hydrocarbon gases

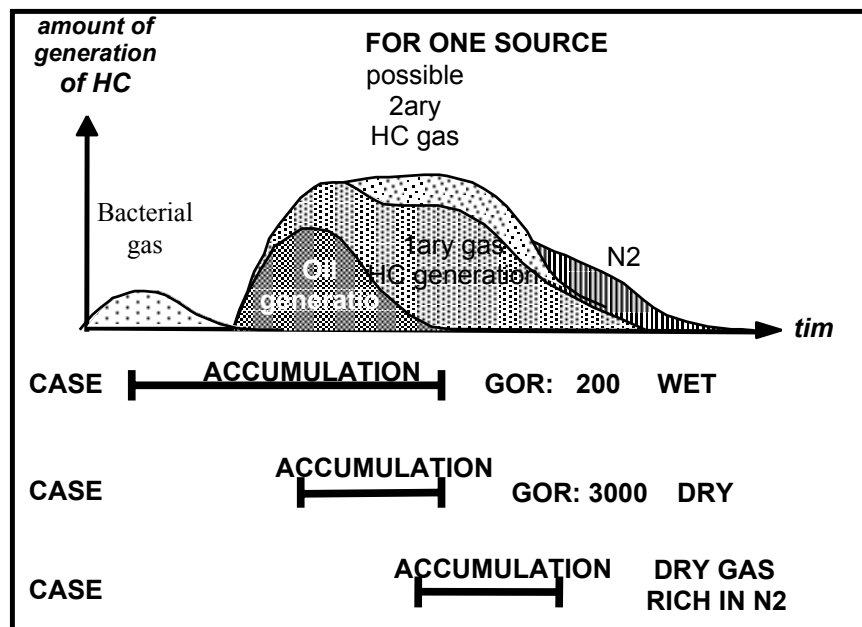


Figure 1: General overview of gas generation

Figure 1 shows a schematic view of the different origins of natural gas. It is important to notice that for high ranges of maturity, gas may come from both the secondary cracking of oil and from the late cracking of the kerogen, these two generation mechanisms corresponding to the temperature range of the “gas window”. Another important parameter has to be considered when attempting to understand an oil and gas system, i.e. the range of accumulate fluids in a reservoir compared to the generated fluids in the source rocks. A purely gaseous accumulation may more easily come from a late closure of a reservoir, accumulating only the products of a late primary cracking rather than a secondary cracking of liquid hydrocarbons.

Distinction of bacterial versus thermogenic gas

A usual way of distinguishing a bacterial imprint versus a thermogenic one in natural gases is the use of the carbon isotopes of methane (Shoell, 1983), the bacterial gas being generally isotopically lighter ($\delta^{13}\text{C} < -55$) than gases generated through thermal cracking. However, Prinzhofer & Pernaton (1997) demonstrated that this distinction is not always straightforward, as isotope segregation during migration may mimic a bacterial signature. Using the two main radiogenic noble gases, it is possible to obtain an independent diagnosis of the origins of the gas. Indeed, it has been observed that the ratio of radiogenic noble gases $^4\text{He}/^{40}\text{Ar}^*$ is very close to the average production ratio in all the thermogenic gases, whereas it is larger in purely bacterial accumulations (Figure 2). This is interpreted as being due to the smaller efficiency of expulsion of ^{40}Ar compared to ^4He from the solid network of the rocks to the fluids (water and hydrocarbons), as already noticed by Elliot et al. (1993) in the gases from the Po area. This new technique applied to petroleum exploration thus segregates the bacterial importance in hydrocarbon exploration, as no chemical nor biological shift may have altered the signature.

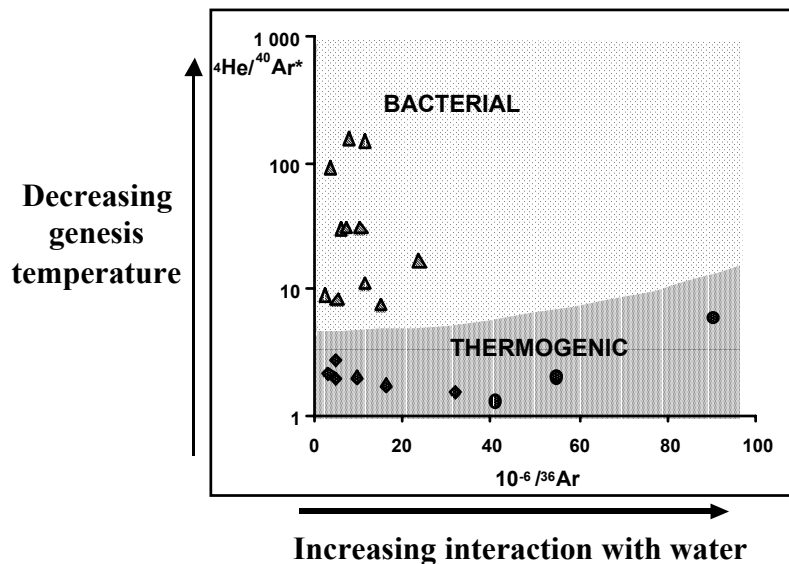


Figure 2: Distinction of bacterial versus thermogenic origins of natural gas using radiogenic noble gas signatures. Data come from the Basin of Macuspana (Mexico) and from Trinidad Island.

Migration of hydrocarbons

In the same way that the ratio $^{13}\text{C}/^{12}\text{C}$ of methane is subjected to fractionation due to migration (Prinzhofer et al., 2000a), the ratios between two isotopes of noble gases may indicate the same process, without the complication with the carbon isotopes that chemical or biological processes may obscure the origin of the fractionation. In several basins, both parameters could be used with

success, giving a consistent migration trend at the scale of the basin or at the scale of the reservoir (Prinzhofer 2000b). The maps based on noble gas data are in fact generally straightforward, with a higher definition of migration paths than carbon isotopes, the latter giving only a general idea of the direction of migration. Figure 3 shows in a Brazilian basin the direction of migration of the hydrocarbons obtained from the fractionation of the $^3\text{He}/^4\text{He}$ ratio. As for the carbon isotopes, the lighter isotope moves faster and is enriched in the area the most distal from the “kitchen”.

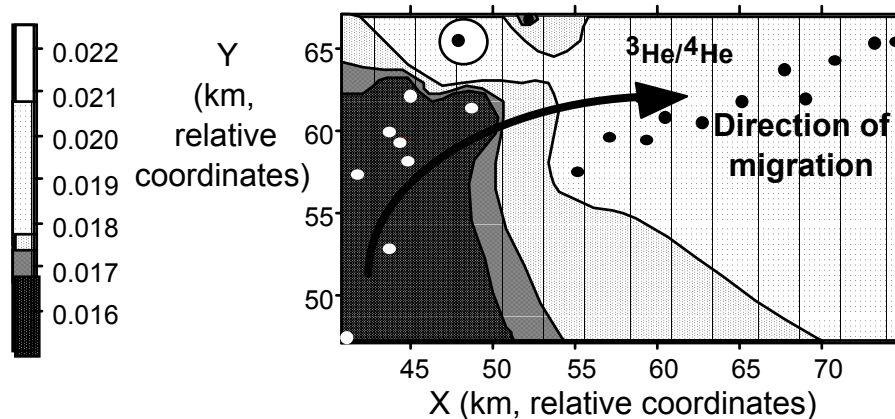


Figure 3: iso-values of the $^3\text{He}/^4\text{He}$ ratio in a Brazilian basin, with the interpreted direction of accumulation of the hydrocarbons in the reservoirs.

In conclusion, the integration of several isotope tracers gives a much more accurate reconstruction of hydrocarbon history, from their generation to their accumulation in reservoirs. The development of such an approach has a high exploratory potential as it uses samples from either a producing well, an exploration well or any gas seep in onshore or offshore areas.

References

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